Argonne NATIONAL LABORATORY

Advanced Technology Vehicle Lab Benchmarking - Level 2 (in-depth)

2014 U.S. DOE Vehicle Technologies Program
Annual Merit Review and Peer Evaluation Meeting

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This presentation does not contain any proprietary, confidential, or otherwise restricted information.

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

U.S. DEPARTMENT OF ENERGY

Overview

- **Timeline**

  2014 Ford Focus BEV
  - Testing complete
  - Final reporting and data out-reach ongoing

  2015 Honda Accord PHEV
  - Preliminary testing complete
  - Break-in complete
  - In-depth testing on-going

- **Budget**
  - FY 2014 $350k
    - Ford Focus BEV
  - FY 2015 $450k
    - Honda Accord PHEV

- **DOE strategic goals/barriers addressed**
  - **F:** Constant advances in technology
  - **D:** Lack of standardized test protocols
  - **E:** Computational models, design and simulation methodologies (Data availability)

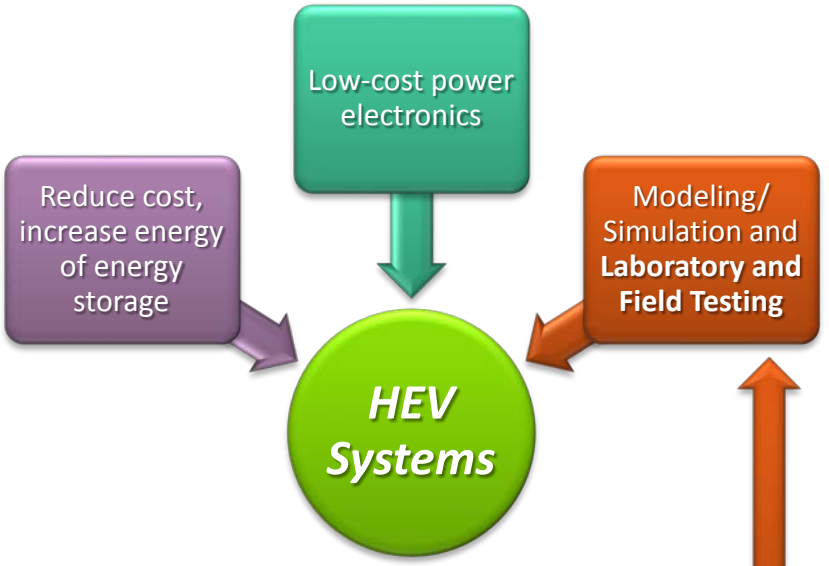
- **Partners**
  - DOE and other National Laboratories
  - USCAR, OEMs, and Suppliers

Relevance: Three Components of HEV Systems

In-depth vehicles selected with DOE, Lab, and OEM input to assess emerging vehicle and component technologies:

- **Ford Focus BEV**:
  - DOE emphasis on increased electric vehicle market penetration and technology development
  - Evaluation of electric vehicle benefits and challenges

"VTO is advancing the large-scale, cost-competitive production of the next generation of electric-drive vehicles through **three complementary component-and system-level technology pathways**:"



Laboratory and Field Testing Objectives

- Establish the state-of-the-art automotive technology baseline for powertrain systems and components through data generation and analysis
- Provide independent evaluation of technology
- Generate data to support target creation and hardware/model validation

Relevance: Purpose and Destination of Data and Analysis

"Knowing how good you are requires an accurate picture of how good everybody else is"

Data and Analysis

D^3 Dynamometer Downloadable Database
www.transportation.anl.gov/D3/
Limited Public data sets

US Drive Tech team support
Full data sets

Supporting DOE

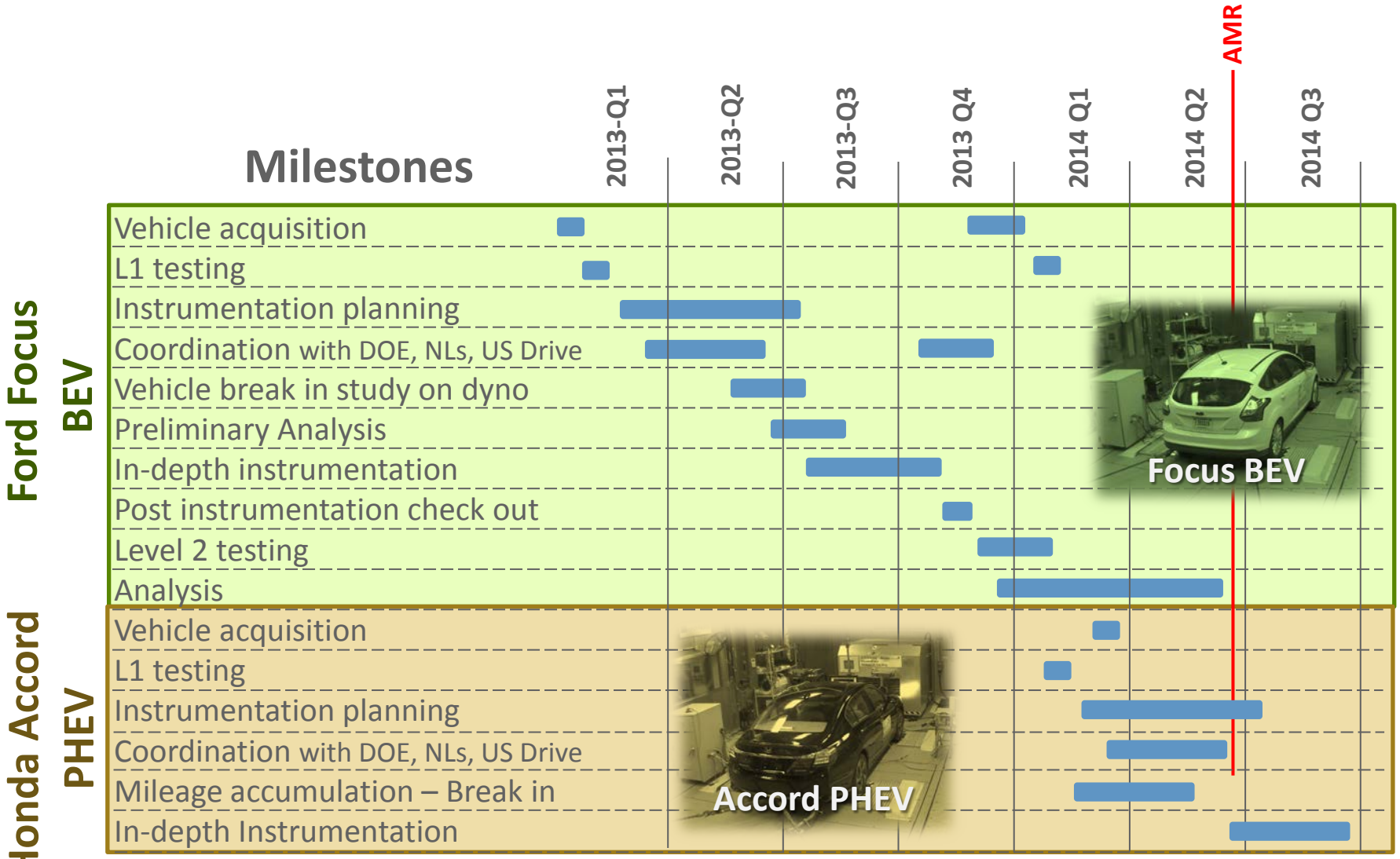
Independent technology evaluation
Baseline for technical targets and goal setting
Component and sub system efficiencies: average over drive cycles at different temperatures as well as efficiency mapping…
Battery system, inverter and motor system, auxiliary loads, power profiles and distributions …

Technology challenge
→ Innovation opportunity
Heating , Accessory loads,….

Codes and Standards
Data for procedures development and validation

Modeling Support
Component mapping
Thermal analysis
Climate control system
Data for validation

Milestones: Providing In-depth Data and Analysis for Components and Vehicles



Approach/Strategy: Vehicle Selection

For highly efficient vehicles, it is important to understand the breakdown of where energy is lost!

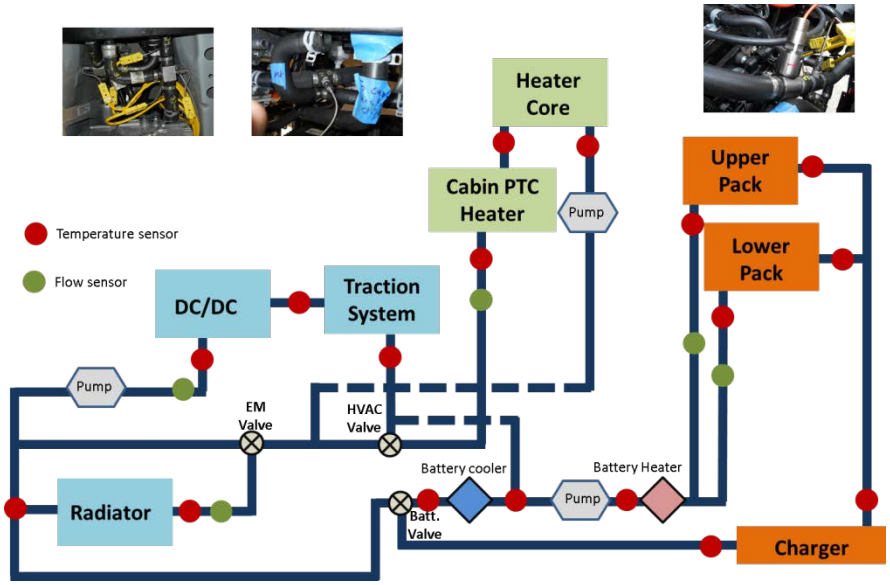
- First in-depth BEV tested at ANL
- Extensive thermal instrumentation…
  - Three main circuits (battery, cabin, powertrain)
  - Temp and flow for nearly every node
  - Coordinated with ANL M+S, NREL, and USCar (Ford) for instrumentation
- Evaluation of electrical loads
  - All pumps, fans, heaters, etc., instrumented with *v* and *I* sensing

MY 2012 Ford Focus BEV http://www.ford.com/cars/focus/trim/electric/	
Vehicle architecture	Single speed BEV (7.82:1 FD reduction ratio)
Test weight	3,750 lbs
Power plant	Main traction motor Permanent magnet 107 kW max reported power 250 Nm max reported torque
Battery	LG Chem/CPI Lithium-ion 23 KWh Total capacity (19.8 Usable) 107 kW Peak observed power 6.6 kW Charger
EPA Label "Fuel" Economy	MPGe: 110 City / 99 Hwy / 105 Cmb.
Performance	Reported 0-60 Time: 9.5 s Top Speed: 84 mph claimed

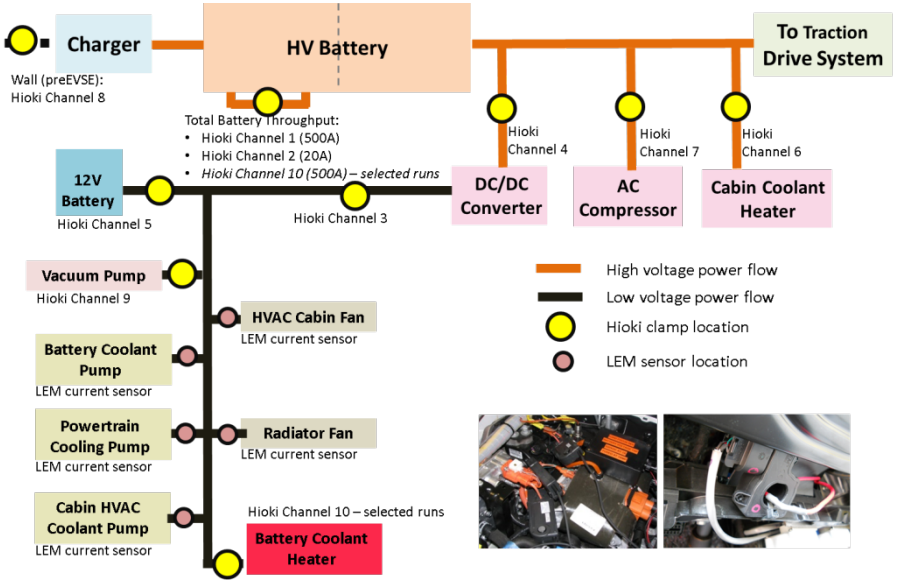
Approach/Strategy: Extensive Vehicle Instrumentation

A wide mix of direct instrumentation, off-line sensors, and CAN bus information was used during testing

Thermal Instrumentation



Electrical Instrumentation



Vehicle was tested across a wide range of US and EU regulatory cycles, real-world cycles, and specialized evaluation cycles. Ambient temperatures ranging from 0F to 95F + Solar load were evaluated to assess the impacts of HVAC on vehicle efficiency and range

Approach/Strategy: Extensive Vehicle Instrumentation

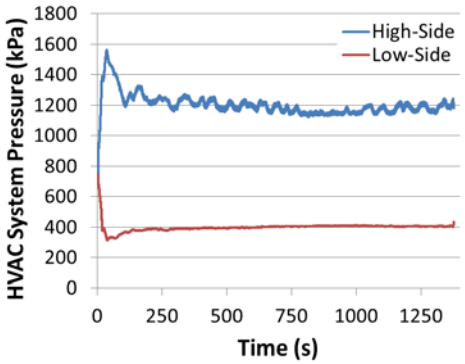
Vehicle air conditioning system was thoroughly instrumented per the requests of several analysis groups

Condenser Inlet Air Temps.

Other A/C Instrumentation

Evaporator_Air_In_Temp[C]

ACComp_Out_Hose_Temp[C]



HVAC_Comp_Press_High[kPa]
HVAC_Comp_Press_Low[kPa]
(Tapped stock veh. Sensors)

Other Signals

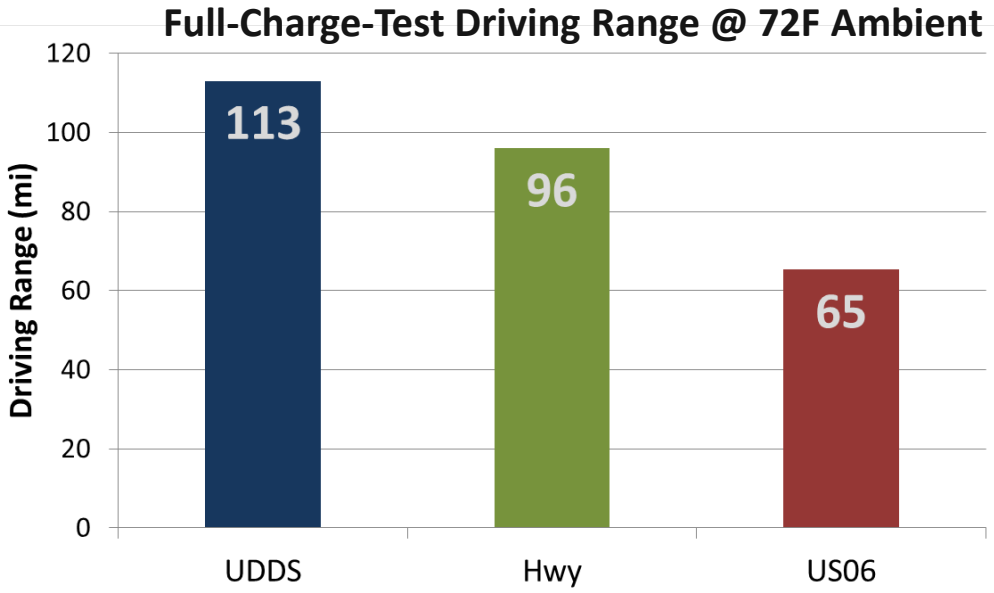
Direct Axle Torque Sensing
Driver axle torque
Passenger axle torque

Highlighted CAN and Scantool-OCR Signals
HVBattery_SOC_OCR
BatteryChargeLimit_OCR
HVBatterySOC_Display_OCR
BatteryCoolantInletTemp_OCR
BatteryDischargeLimit_OCR
BatteryTemperature_OCR
OutdoorTemp_OCR
Batt_SOC_CAN[%]
Brake_Pedal_Press_CAN[]
Brake_Pedal_Press2_CAN[]
AC_Switch_State_CAN[I/O]
Motor_Spd_CAN[RPM]
Pedal_Accel_Pos_CAN[%]
Wheel_Spd_1_CAN[MPH]
Wheel_Spd_2_CAN[MPH]
Wheel_Spd_3_CAN[MPH]
Wheel_Spd_4_CAN[MPH]
Motor_Clnt_Temp_CAN[C]
Brake_Switch_State_CAN[I/O]
PRNDL_Pos_CAN[]
Batt_Current_CAN[A]
Batt_Voltage_CAN[V]
HVAC_Fan_Demand_CAN[]
AC_Off_State_CAN[]
HVAC_Vent_Lower_State_CAN[]
HVAC_Vent_Front_State_CAN[]
HVAC_Vent_Defrost_State_CAN[]
HVAC_Recirc_State_CAN[]
HVAC_Temp_Setting_Driver_CAN[]
HVAC_Temp_Setting_Passenger_CAN[]
HVAC_Defrost_Rear_State_CAN[]

Accomplishments: US Cycle Testing (Full Depletion)

- Vehicle shows 65-113 mile full depletion range depending on cycle aggressiveness
- Peak traction power from battery observed at roughly 107 kW (regen. 56 kW)
- Roughly 85% SOC swing during full depletion from full charge

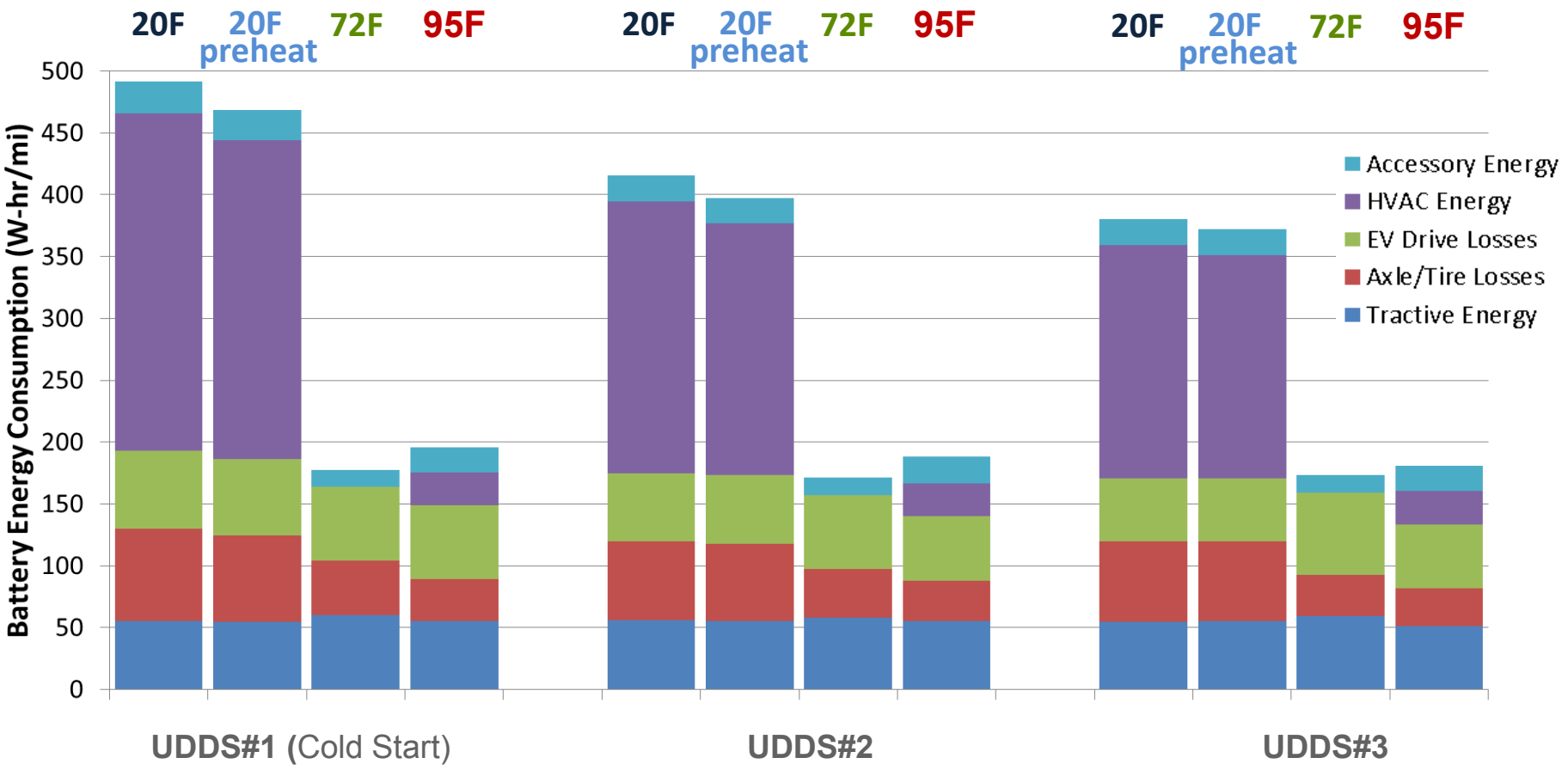
Claimed Total Capacity	23	kW-hr
Total Usable Capacity	19-19.5	kW-hr
SOC Swing	85	% SOC
Battery Utilization	83-85	%
Peak Discharge Power	107	kW
Peak Recharge Power	56	kW
Peak Axle Torque	1924	Nm
Drive Axle Power	98	Kw
Full Charge Time	3.6	hr (@ 6.6 kW)



Accomplishments: Energy Allocation versus Ambient Temp.

Looking at the relative break-down of energy provides more insight into losses

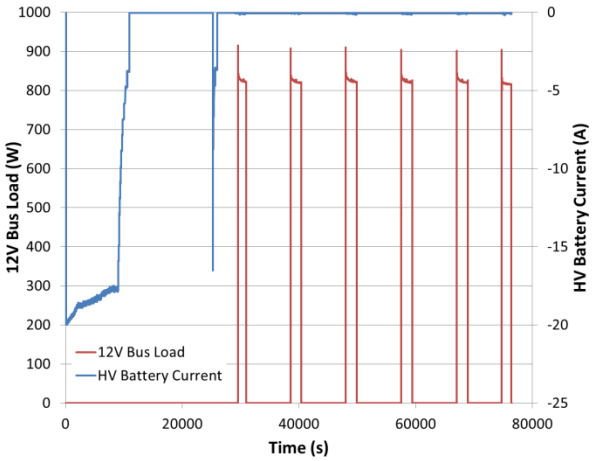
- Axle losses interact with HVAC loading to over/under emphasize the penalty associated with heater/air-conditioning at more extreme ambient temperatures



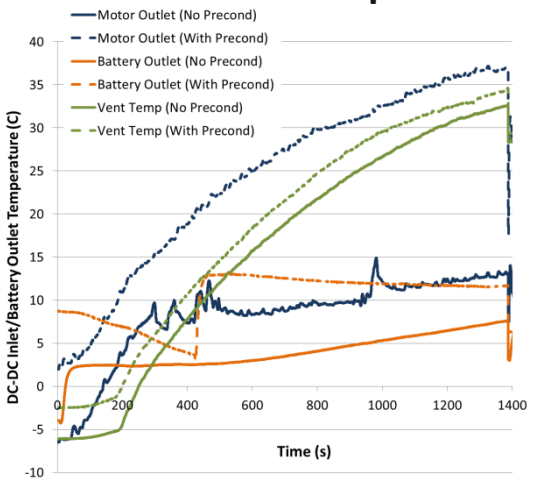
Accomplishments: Battery Preconditioning Example

- Focus BEV testing highlights that integrated cooling loops used with battery preconditioning may lead to secondary benefits such as reduced heating loads since overall system temperatures are increased

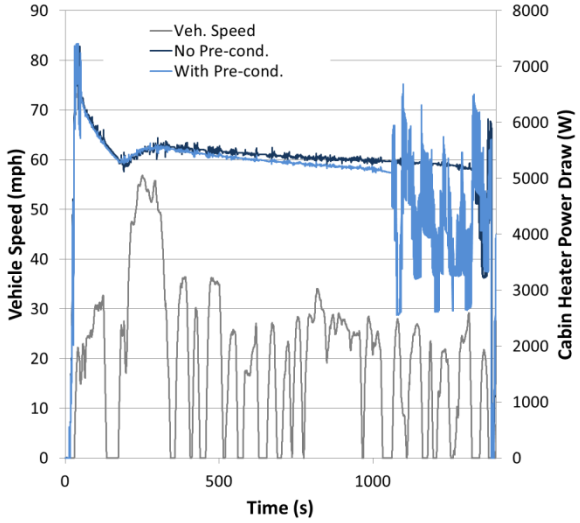
Battery Conditioning During Charge



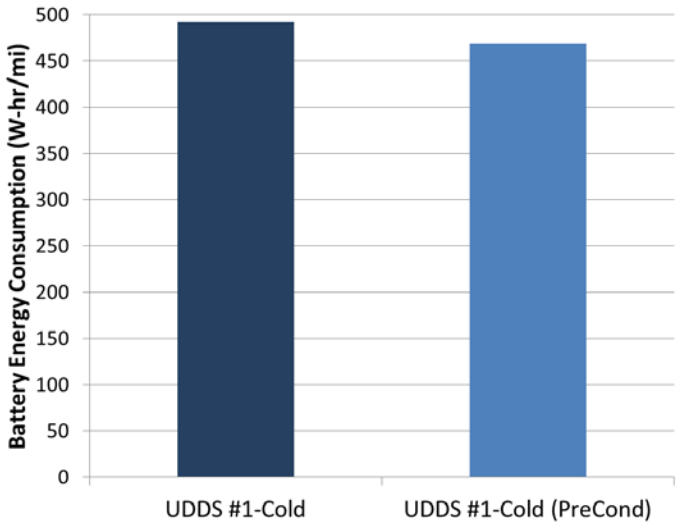
Conditioning leads to elevated coolant temps



Reduced heater loading for preconditioned case



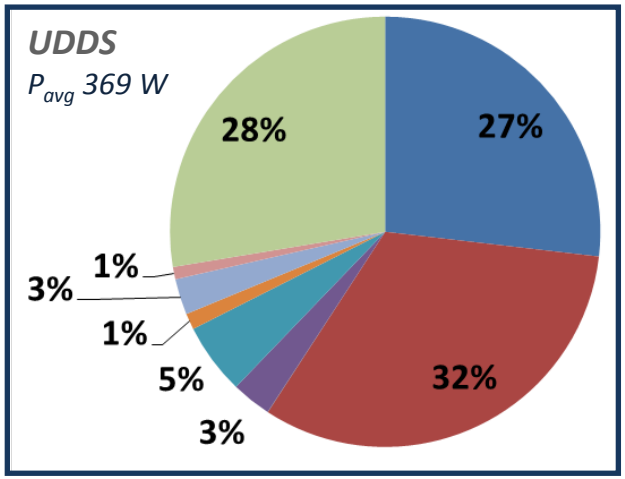
Roughly 5% less battery energy consumption for precond. case



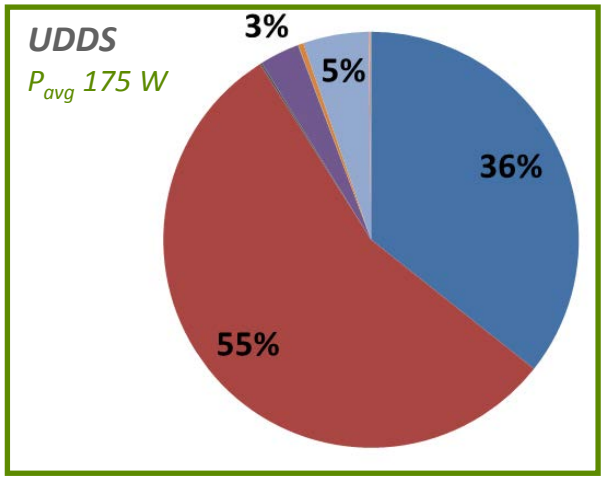
Accomplishments: 12V Accessory Load Break-down

Detailed electrical instrumentation allows for the impacts of various loads to be evaluated and quantified relative to operation

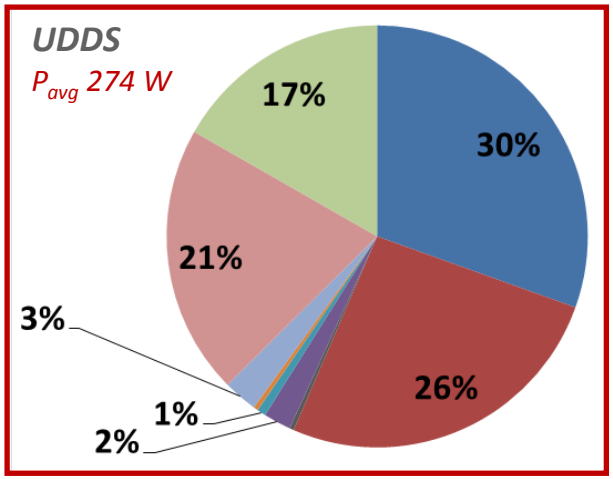
20F Ambient

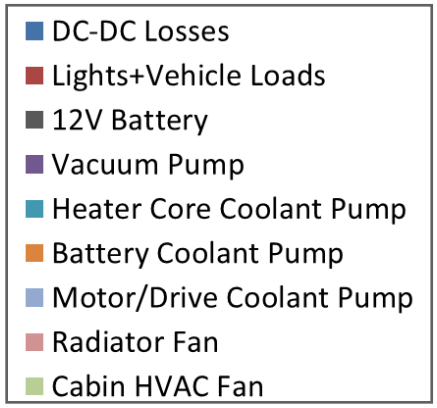


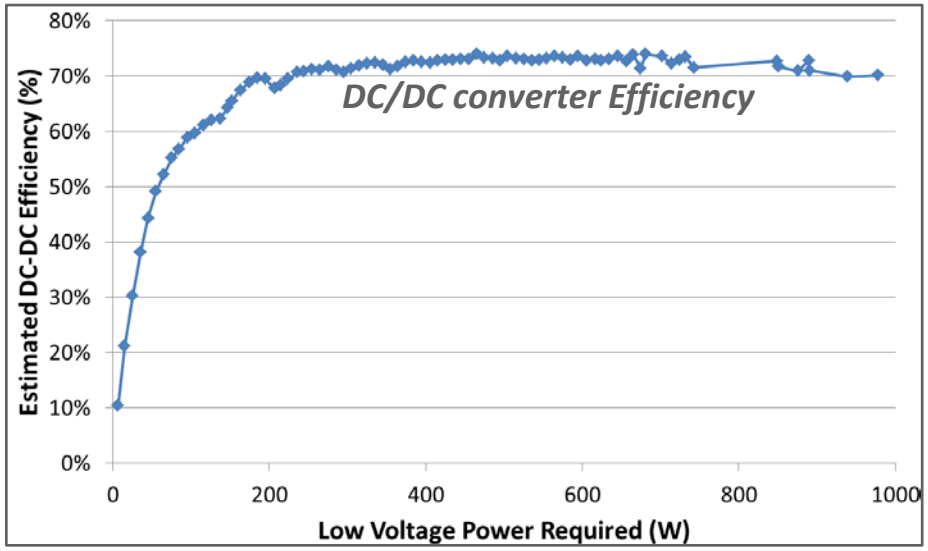
72F ambient



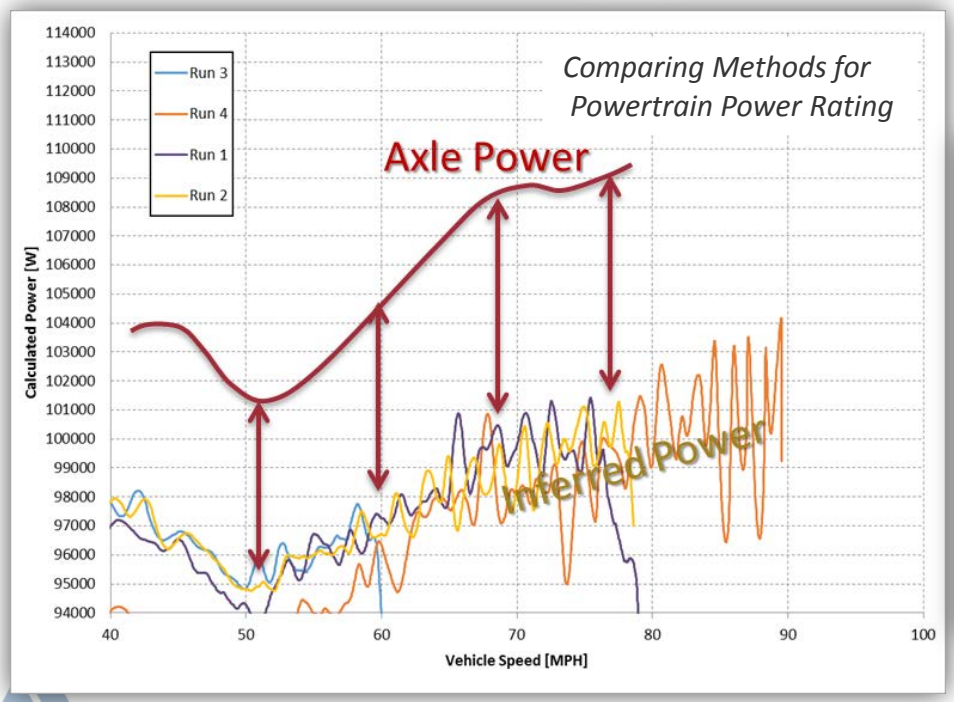
95F ambient + 850W/m²

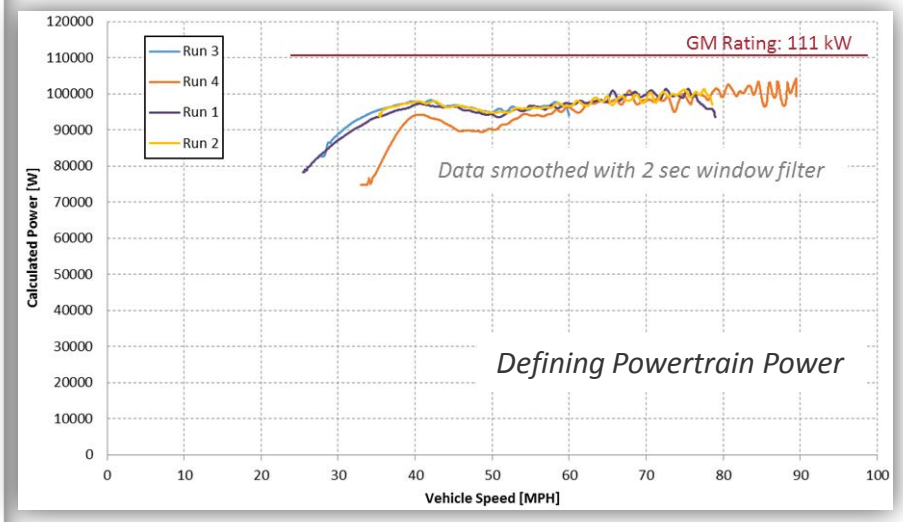






Accomplishments: In-depth Testing for SAE Hybrid Powertrain Power Test Support (J2908)





Collaborations and Coordination with Other Institutions

In-depth Benchmarking Informs Many Stakeholders

J1711 HEV & PHEV test procedures
J1634 EV test procedures
J2908 Hybrid Powertrain Power

SAE International

AVTA (Advanced Vehicle Testing activities)
- In-depth vehicle and component evaluation

INL Idaho National Laboratory · Argonne National Laboratory

In-depth Benchmarking

DOE technology evaluation
- DOE requests
- National Lab requests

NREL · ornl Oak Ridge National Laboratory · INL Idaho National Laboratory · Argonne National Laboratory

Autonomie
- Support of modeling and simulation with data

AUTONOMIE

USDRIVE, tech teams and OEMs
- Shared test plans, data and analysis

USDRIVE Driving Research and Innovation for Vehicle Efficiency and Energy Sustainability

Summary

Research Highlights:

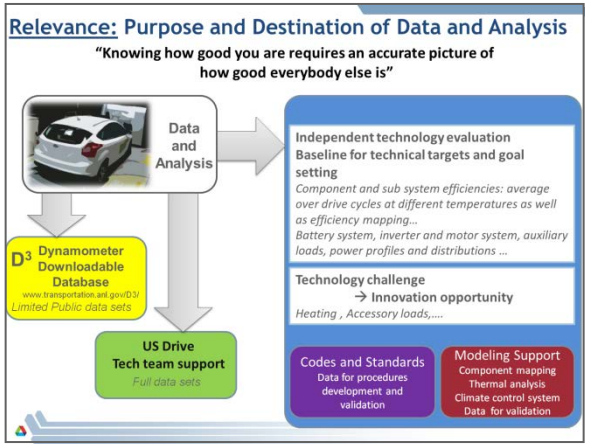
- Energy break-down supports DOE's high-level push toward increased battery capacity and lower mass/road-loads for dramatically increased vehicle range. (while retaining the need for other improvements)
- Reduced axle/tire losses appear to be an area in which improvements can be broadly applied.
- Impact of cold operation (heater) is significantly larger than that of hot operation (air conditioning). Both depend on cycle tractive power.

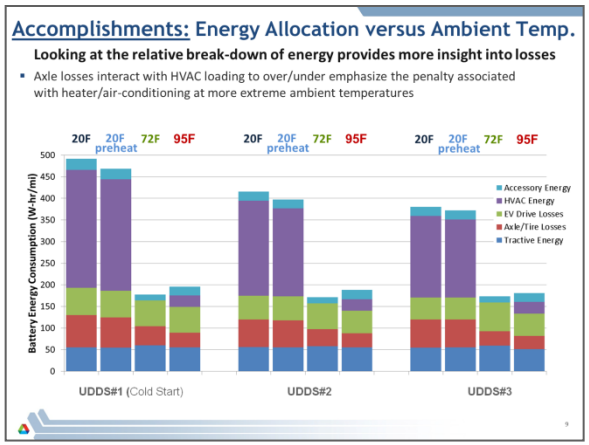
Data Dissemination

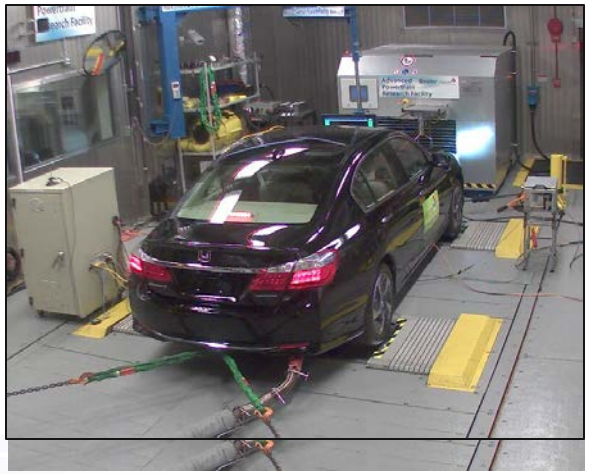
- Full data sets posted to USDrive website for stakeholders
- Partial datasets posted to ANL D3 for public access
- Several SAE and related journals/presentations regarding in-depth testing g, results, and analysis

Future/On-going Work

- In-depth Honda Accord PHEV testing on-going

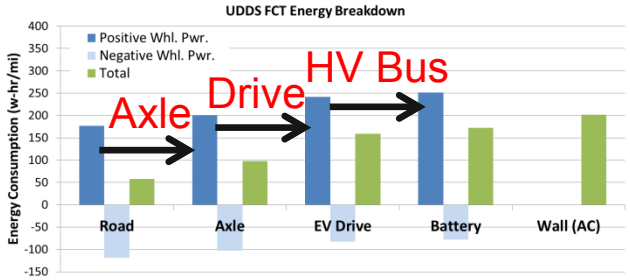


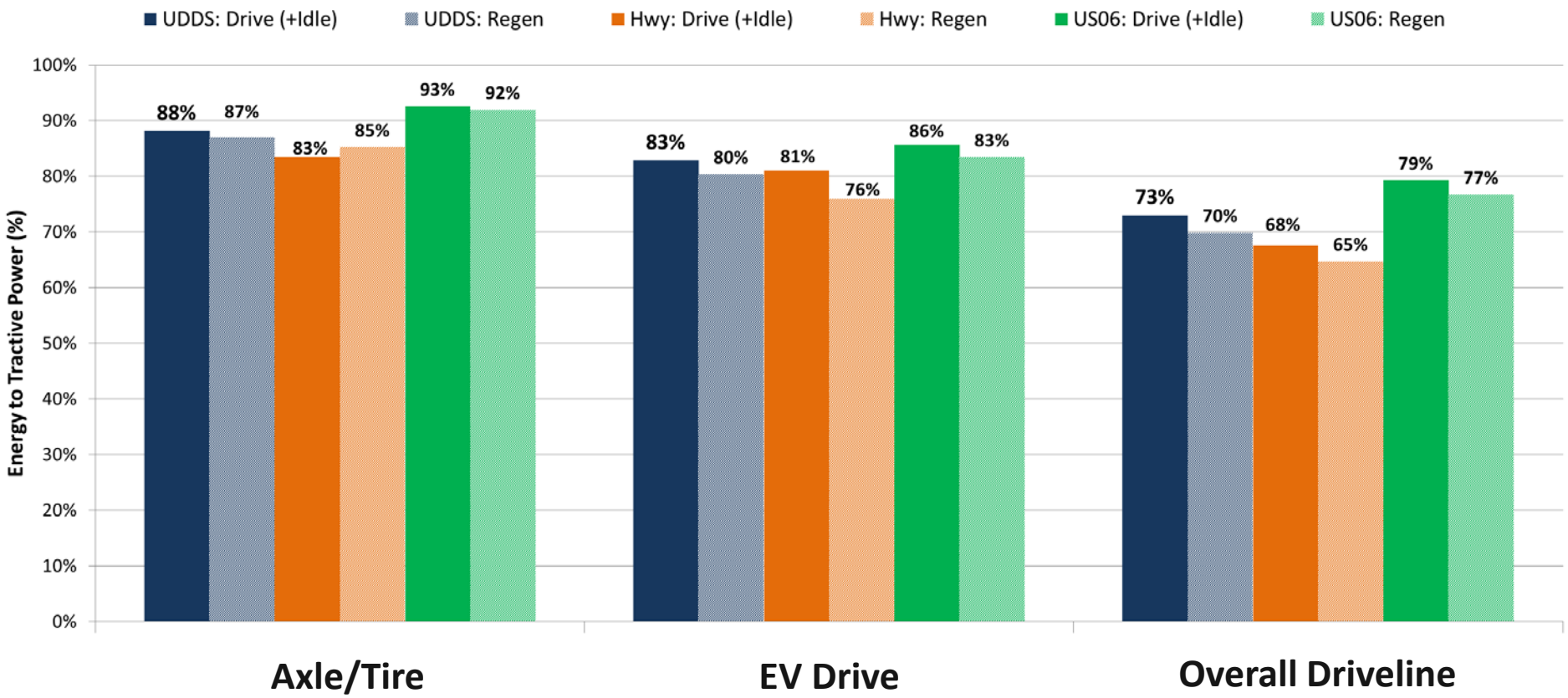




Background Slides

Tractive Efficiency Analysis





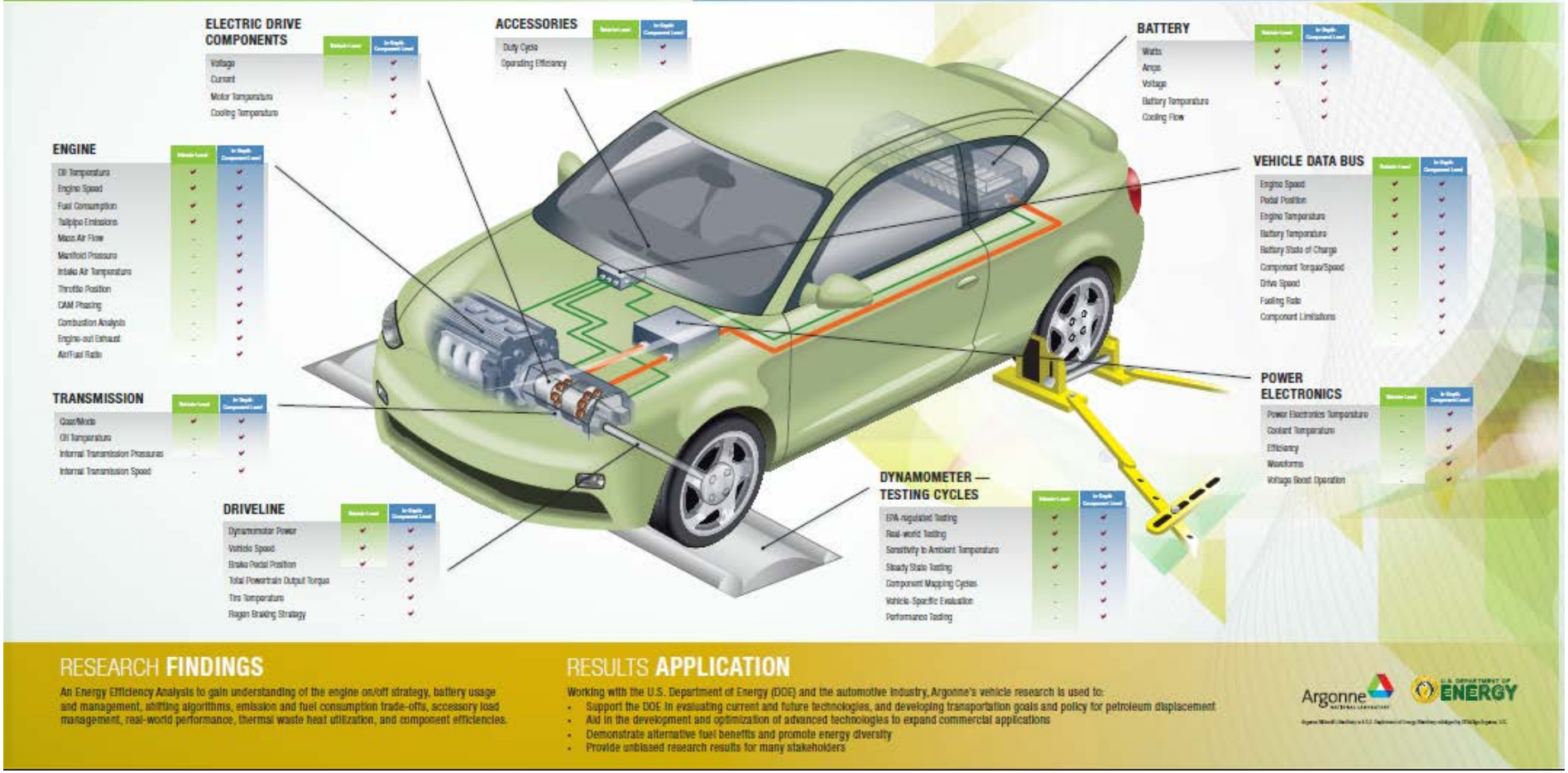
Advanced Vehicle and Component Research at Argonne's APRF

VEHICLE-LEVEL BENCHMARK RESEARCH

Vehicle-Level Benchmark Research is the initial testing performed on a wide variety of vehicles at Argonne's Advanced Powertrain Research Facility (APRF). Engineers use the facility's two-wheel drive and four-wheel drive dynamometers and state-of-the-art instrumentation to reveal important information on performance, fuel economy, energy consumption and emissions output. This data, which seeks to broadly understand a specific vehicle, is critical to evaluating the progress and viability of current and future transportation technologies.

IN-DEPTH VEHICLE AND COMPONENT-LEVEL RESEARCH

In-Depth Vehicle and Component-Level Research takes vehicle evaluation a step further with invasive instrumentation and extensive testing to reveal even more significant data and insight. By outfitting vehicles with equipment such as torque sensors, power analyzers and thermocouples, researchers attain a more complete vehicle assessment, including detailed component mapping and operating strategy evaluation. As compared to the standard Vehicle-Level Benchmark Research, this in-depth approach provides more comprehensive data, component characterization and understanding of the powertrain system operation. The schematic below illustrates the varying levels of data provided by the two types of vehicle evaluation.



RESEARCH FINDINGS

An Energy Efficiency Analysis to gain understanding of the engine on/off strategy, battery usage and management, shifting algorithms, emission and fuel consumption trade-offs, accessory load management, real-world performance, thermal waste heat utilization, and component efficiencies.

RESULTS APPLICATION

Working with the U.S. Department of Energy (DOE) and the automotive industry, Argonne's vehicle research is used to:

- Support the DOE in evaluating current and future technologies, and developing transportation goals and policy for petroleum displacement
- Aid in the development and optimization of advanced technologies to expand commercial applications
- Demonstrate alternative fuel benefits and promote energy diversity
- Provide unbiased research results for many stakeholders

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